Mu2e-doc-397-v1

The Mu2e Experiment: An Overview

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Presentation to CD/ADSS

October 20, 2008

The MECO Experiment

- Muon to Electron COnversion
  - Mu2e detector design is a copy of MECO
  - Basic beam structure also copied from MECO.
  - Essentially 1990's technology.
    - Lots of opportunity to improve on this.
    - Therefore lots of work to do, especially simulations.
- MECO:
  - Approved for BNL; reached about CD1.
  - MECO(NSF HEP) but BNL(DOE Nuclear Physics).
    - Died in a dispute over $ for AGS.
- Mu2e and FNAL: both DOE HEP.
- Many MECO collaborators on Mu2e.
- Almost all numbers/figures are from MECO.

Episode IV: A New Hope

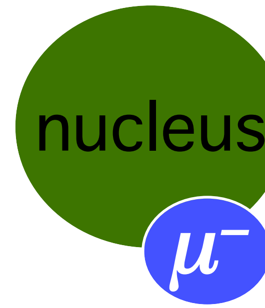
- Recent P5 Report about Mu2e:

“The experiment could go forward in the next decade with a modest evolution of the Fermilab accelerator complex. Such an experiment could be the first step in a world-leading muon-decay program eventually driven by a next-generation high-intensity proton source. **The panel recommends pursuing the muon-to-electron conversion experiment... under all budget scenarios considered by the panel”**

- Mu2e will go to the PAC in their Nov/08 meeting.
- Working Schedule:
  - CD0 in February 2009
  - CD1 in Fall 2010.

Start the Story in the Middle

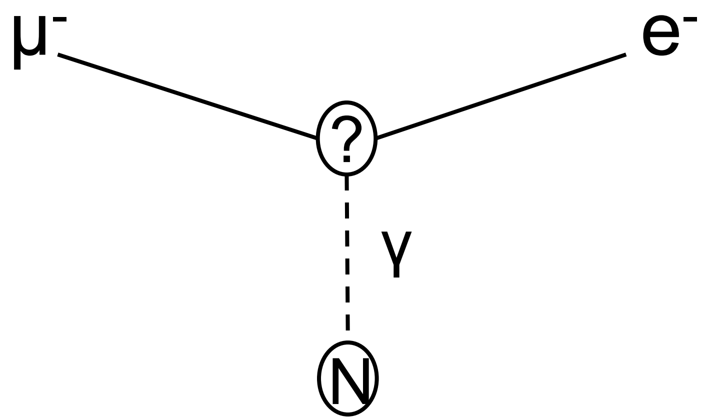
- Make muonic Al
  - Lifetime 864 ns.
- Watch it decay:
  - Decay-in-orbit (DIO): 40%
    - Dominant background.
  - Capture on Nucleus: 60%
    - Normalization.
  - Neutrinoless muon to electron conversion.
    - A very, very, small fraction, if at all.
- Lots of backgrounds …



Bohr radius ≈ 20 fm

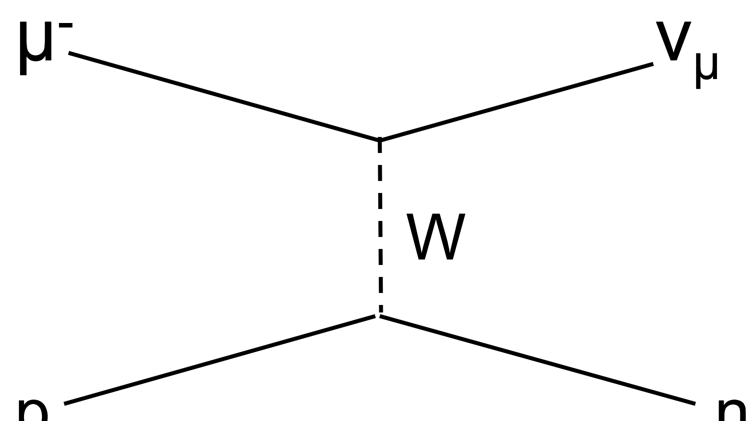
Al nuclear radius ≈ 4 fm

Mu to e Conversion



Coherent = no nuclear breakup

Nuclear Capture



In general will have nuclear breakup

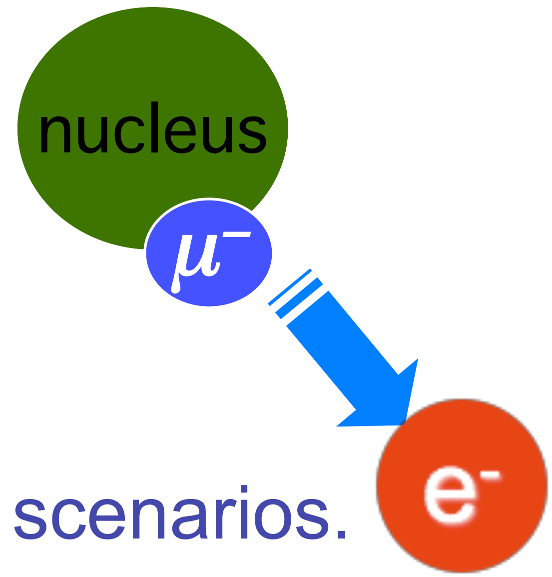
Measured quantity is:

$$R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1))}$$

Neutrinoless μ to e Conversion

$$\mu^- N \rightarrow e^- N$$

- Single mono-energetic electron.
- Energy depends on Z of target
  - For Al, $E_e \approx 105$ MeV.
- Recoiling nucleus (not observed).



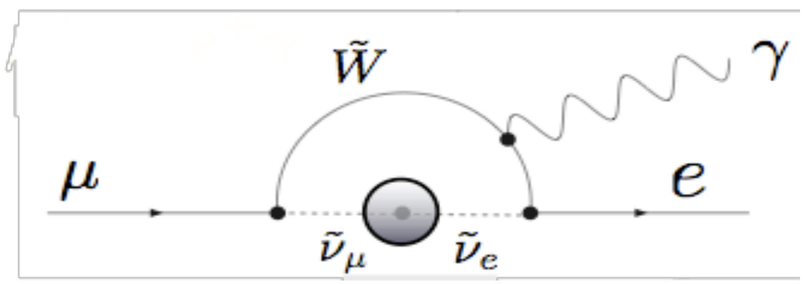
- Negligible rate in SM.
- Observable in many New Physics scenarios.
- Charged Lepton Flavor Violation:

$$\mu \rightarrow e\gamma \quad \mu \rightarrow e^+e^-e^+ \quad K_L^0 \rightarrow \mu e \quad B^0 \rightarrow \mu e$$

$$\tau \rightarrow \mu\gamma \quad \tau \rightarrow \mu^+\mu^-\mu^+ \quad D^+ \rightarrow \mu^+\mu^+\mu^-$$

Rates in the Standard Model

- With massive neutrinos, non-zero rate in SM.
- Too small to observe.

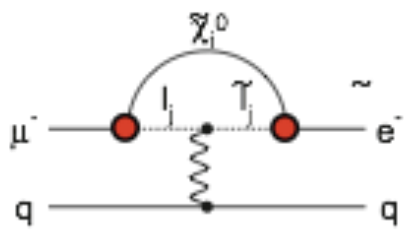


$$\mathrm{BR}(\mu \to e\gamma) \;=\; \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

NP Scenarios have Rates O(10^{-15})

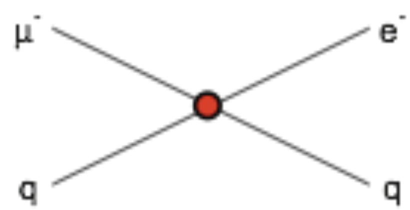
Supersymmetry

rate ~ 10^{-15}



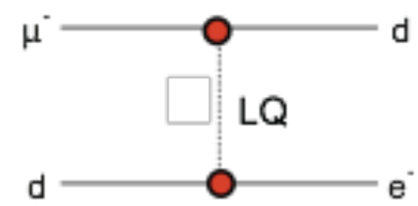
Compositeness

Λ_c ~ 3000 TeV



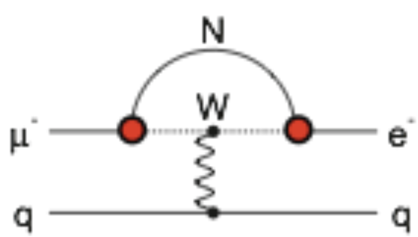
Leptoquark

M_{LQ} =
3000 $(\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2



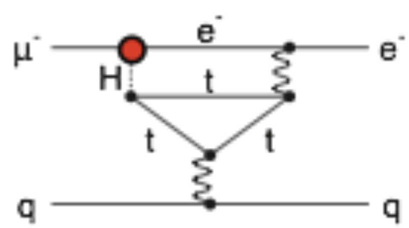
Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2$ ~ 8×10^{-13}



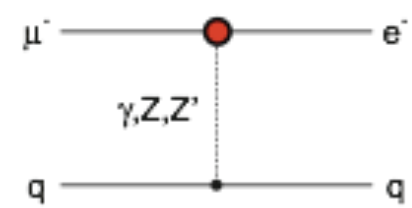
Second Higgs Doublet

$g(H_{\mu e})$ ~ $10^{-4}g(H_{\mu\mu})$



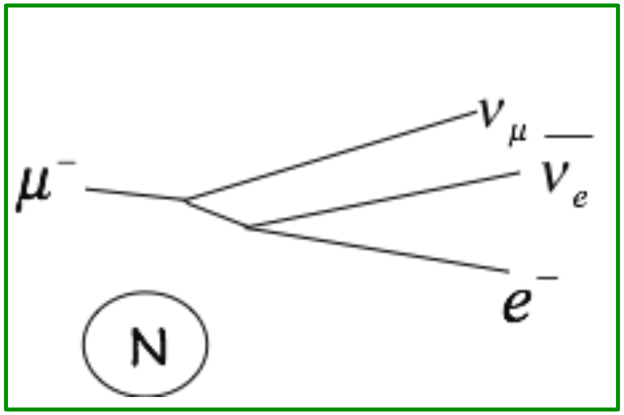
Heavy Z' Anomal. Z Coupling

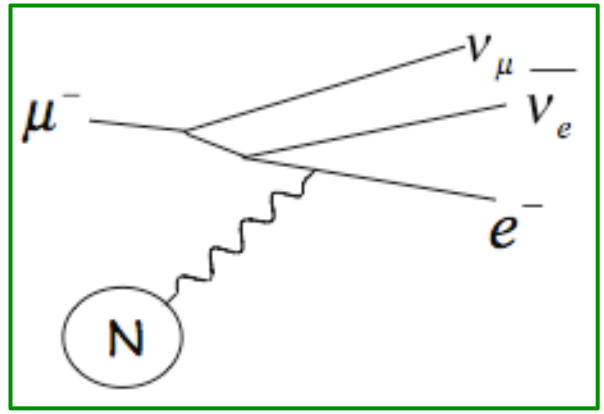
$M_{Z'}$ = 3000 TeV/c^2



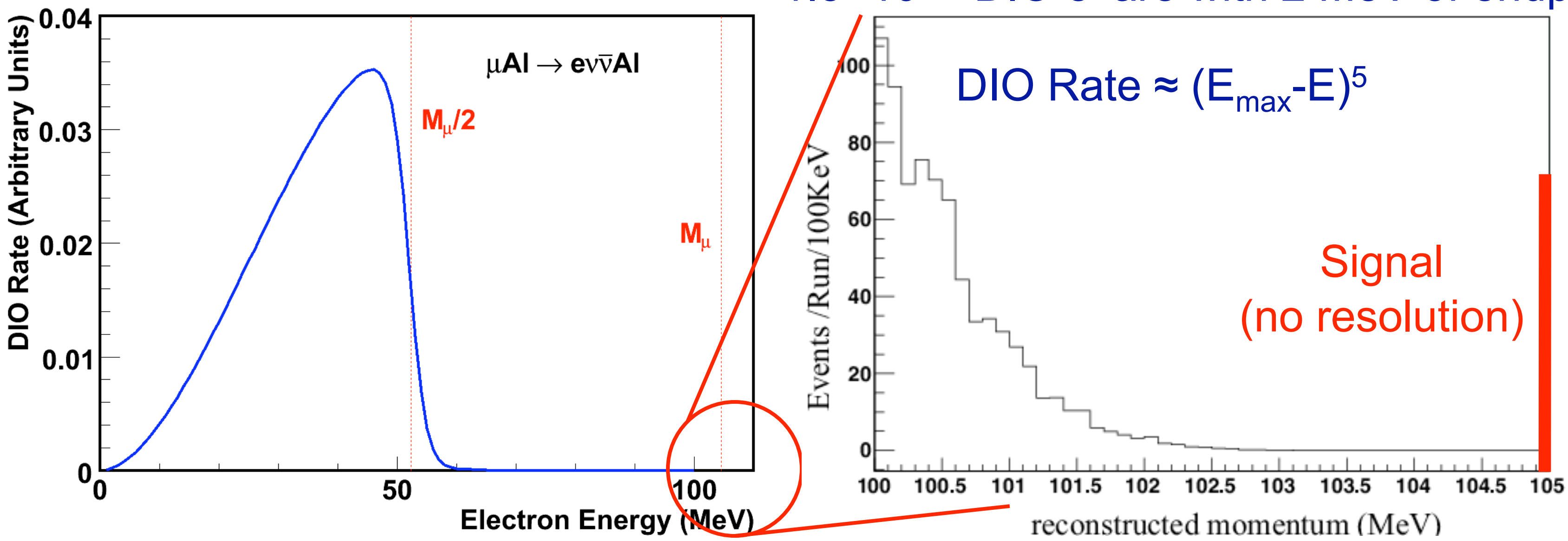
also see Flavour physics of leptons and dipole moments, arXiv:0801.1826

Decay-in-Orbit: Dominant Background



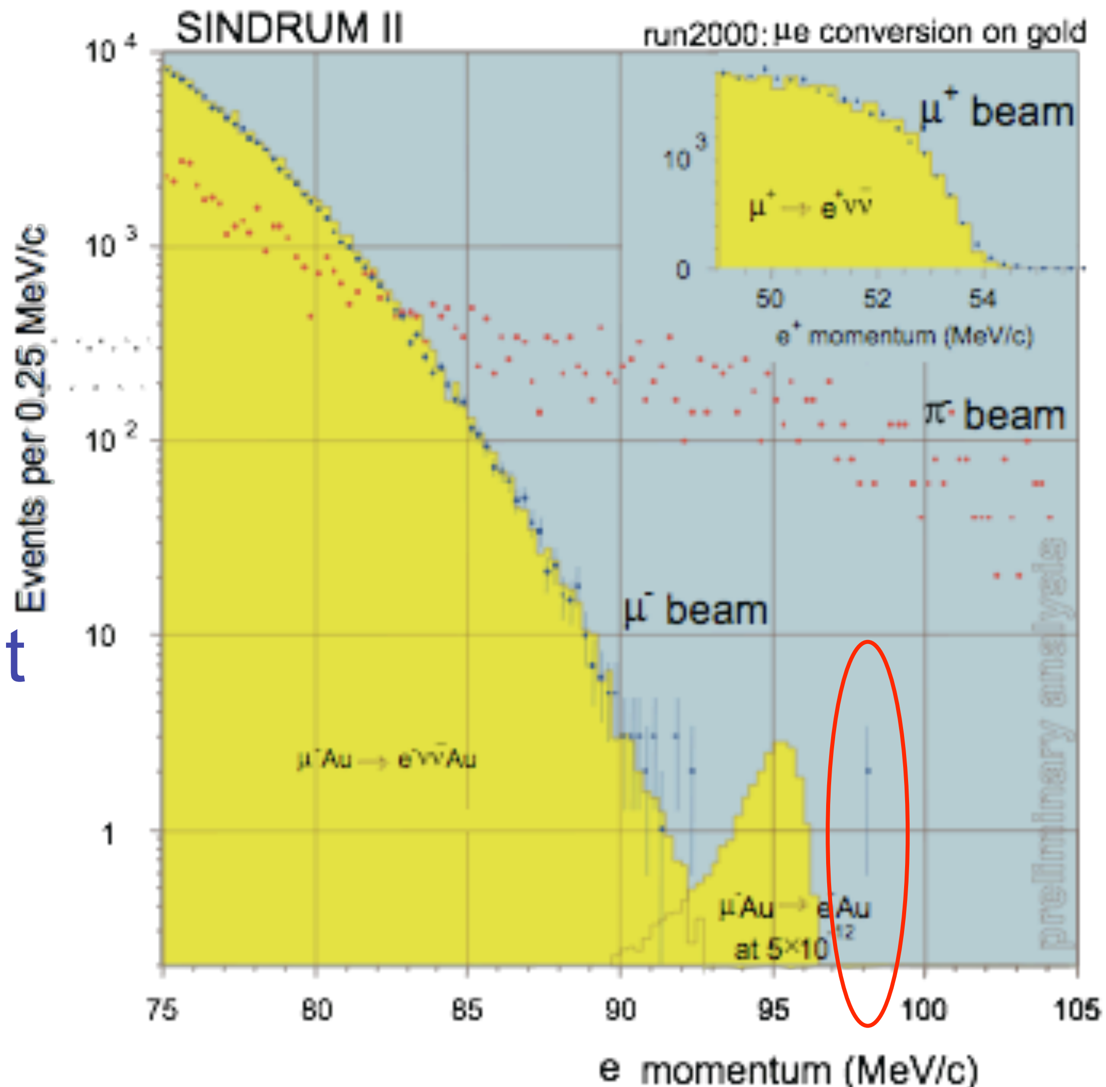


1.5×10^{-15} DIO e^- are with 2 MeV of endpoint.



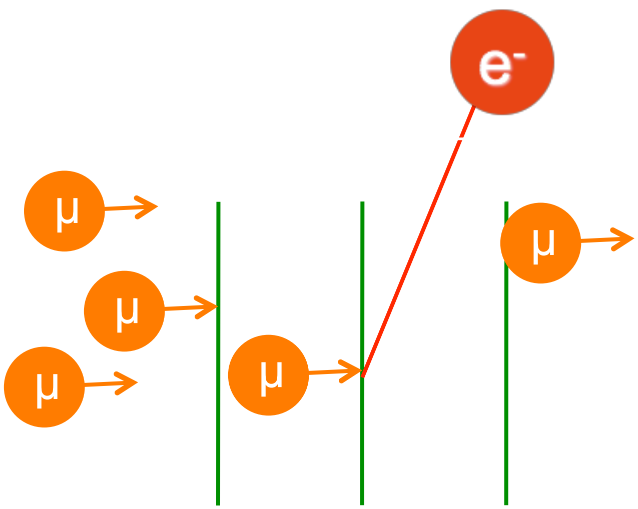
Previous Best Experiment

- SINDRUM II
- $R_{\mu e} < 6.1 \times 10^{-13}$ @90% CL
- 2 events in signal region
- Au target: different endpoint than Al.



A Cartoon of the Experiment

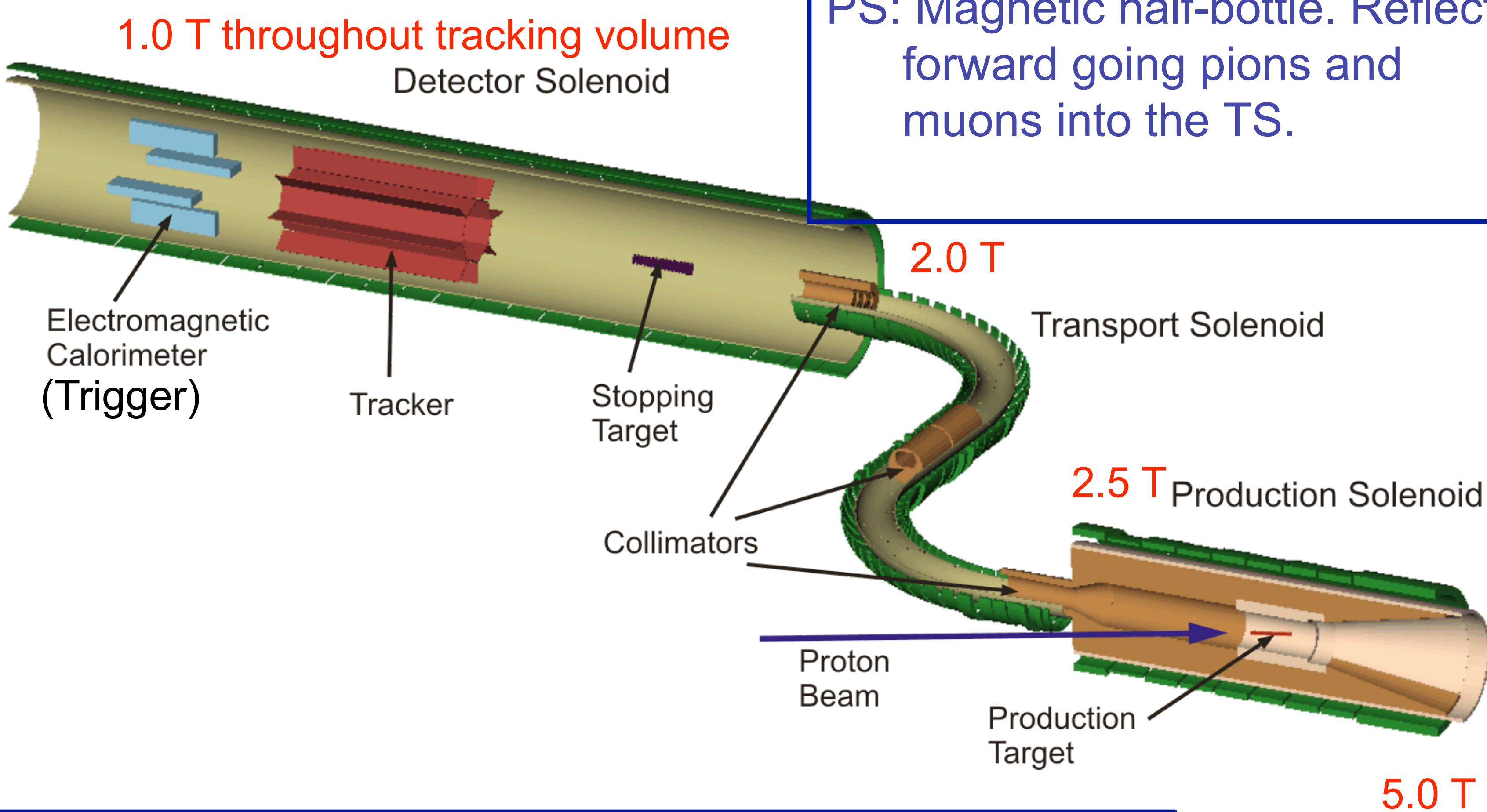
- Muon pulse on thin Al target foils; capture.
- Wait for prompt backgrounds to go away, 700 ns.
- Measure E_e for electrons for 900 ns.
- Repeat every 1.7 μs.
- Look for peak at endpoint of E_e spectrum.



- 17 targets
- 200 microns thick
- 5 cm spacing
- Radius:
  - 8.30 cm at upstream
  - 6.53 cm at downstream

Footprint 12.2 m × 25.7 m

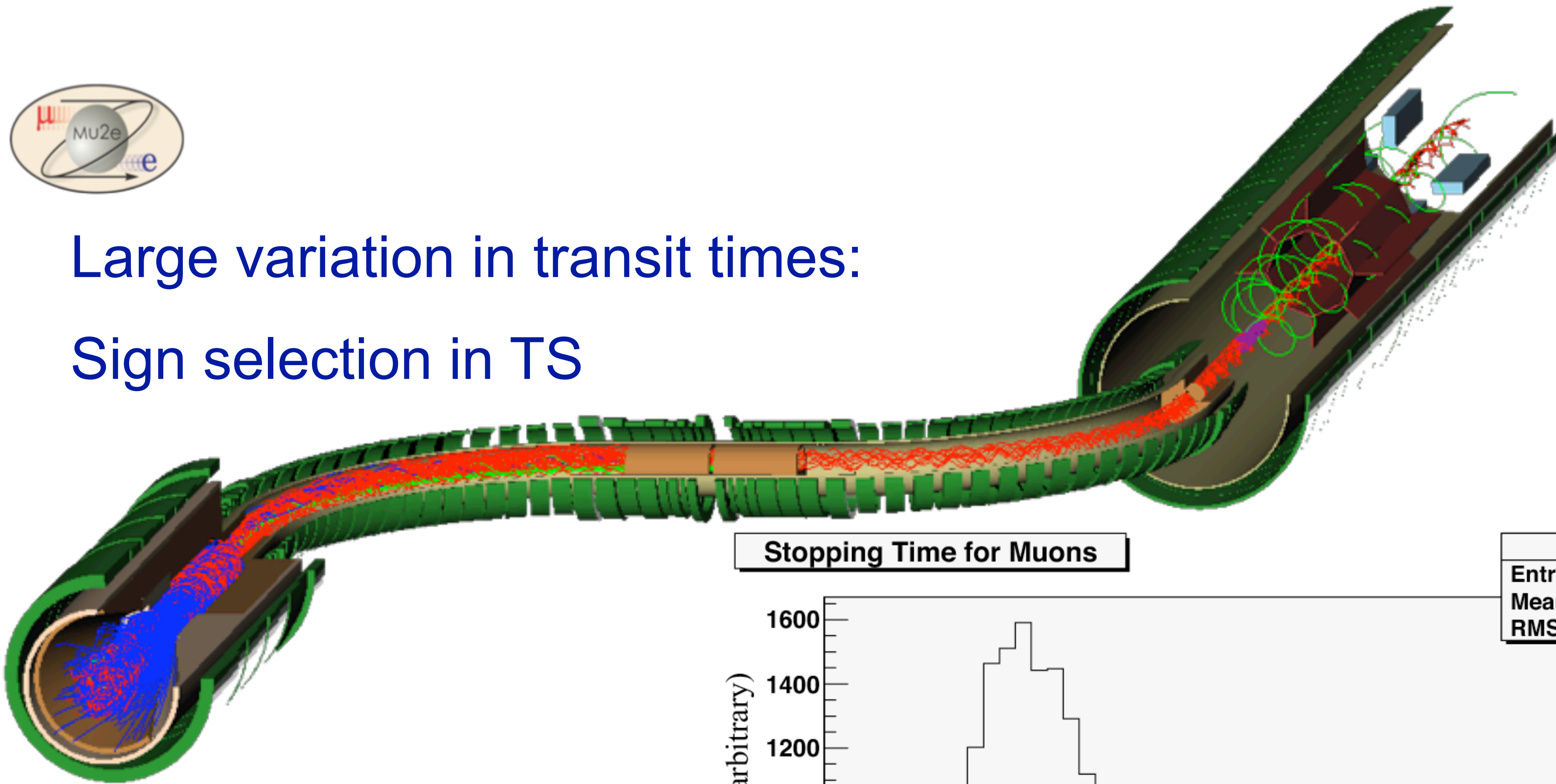
PS: Magnetic half-bottle. Reflects forward going pions and muons into the TS.



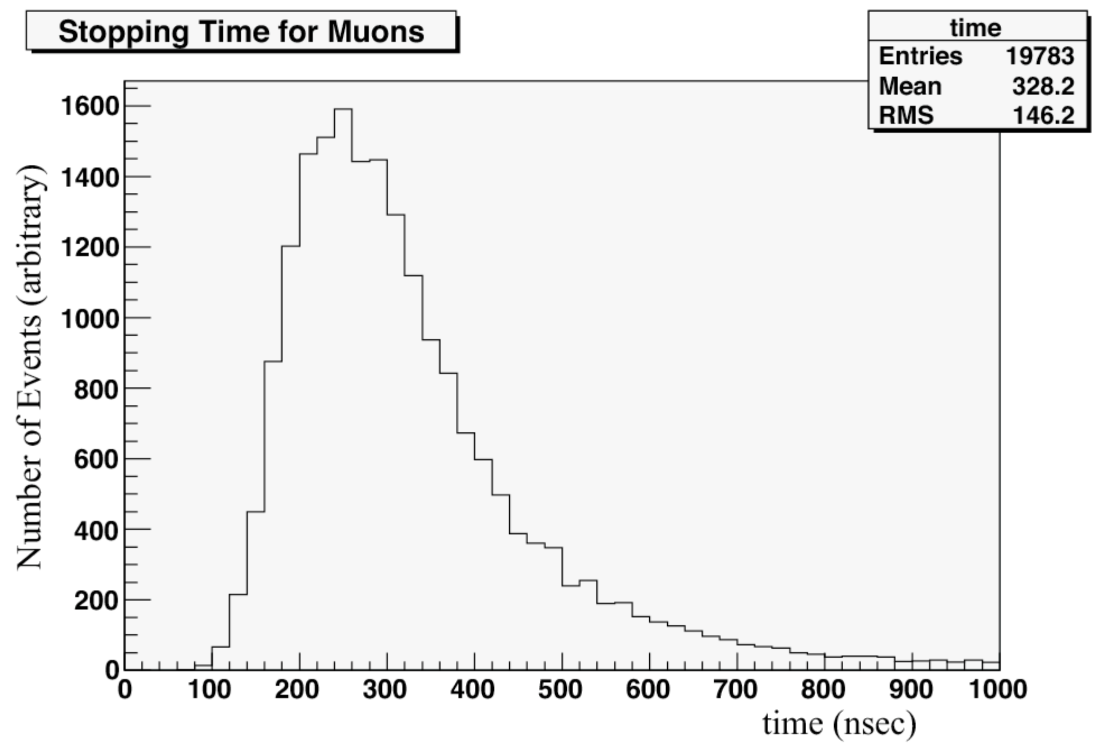
No line of sight from production target to stopping target.

Large variation in transit times:

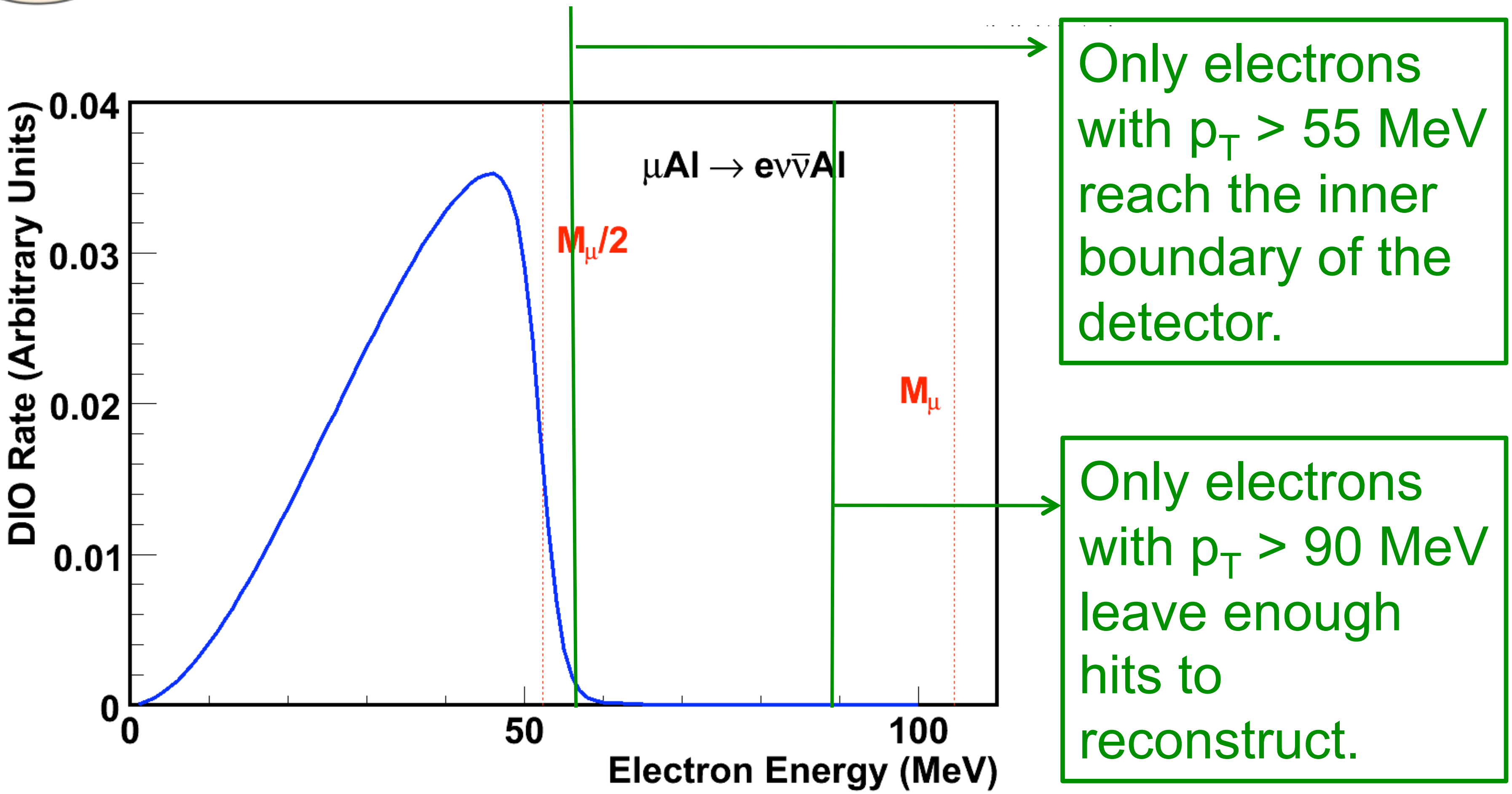
Sign selection in TS



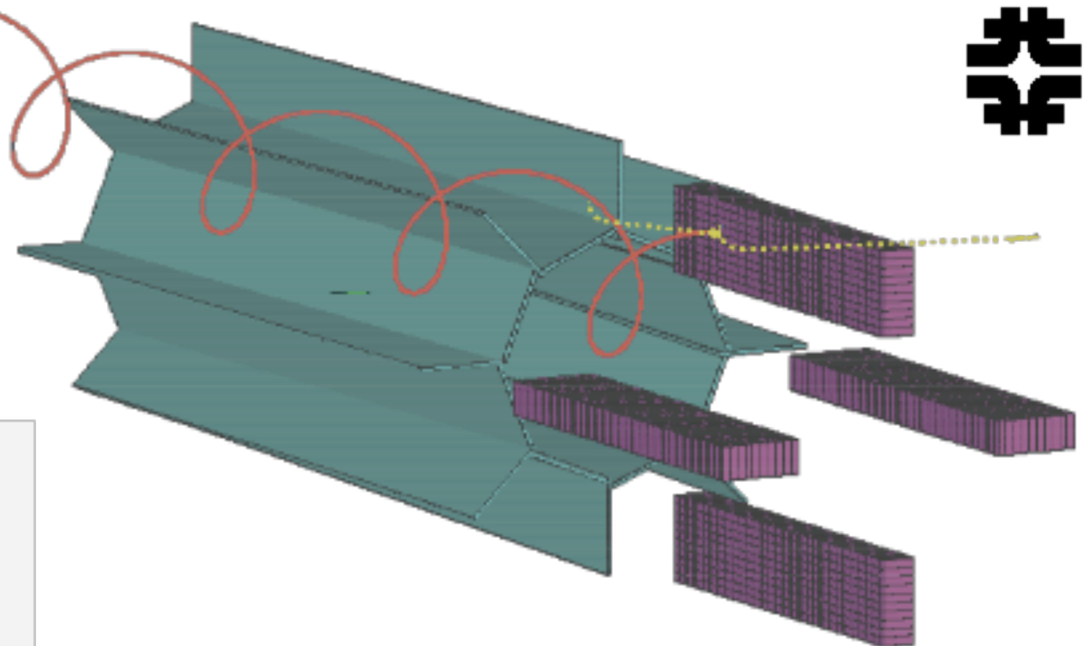
Electrons, pions, kaons etc arrive before and with the muons.

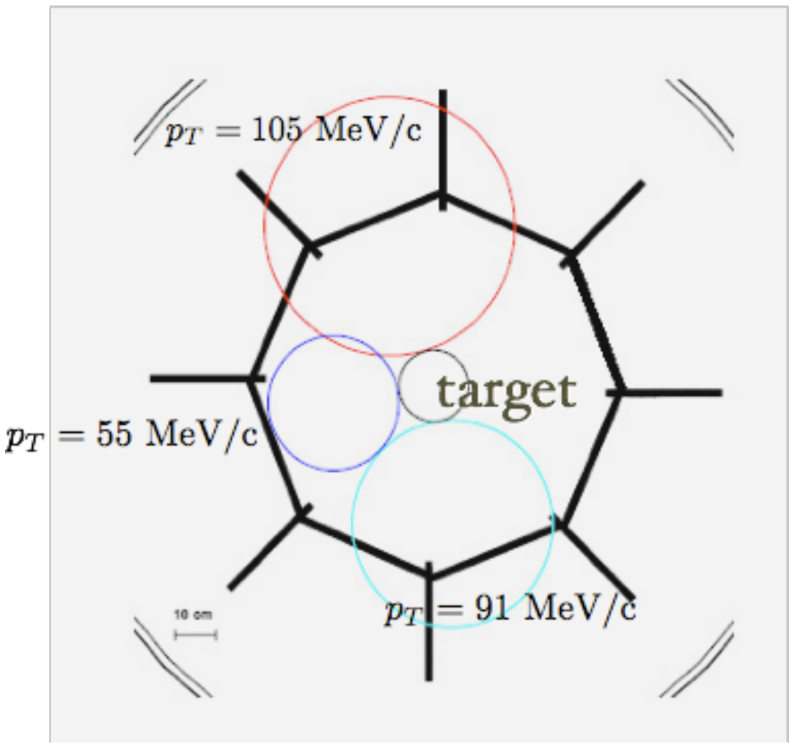


How do you measure 1 in 10^{17} ?



Baseline Design: L-Tracker

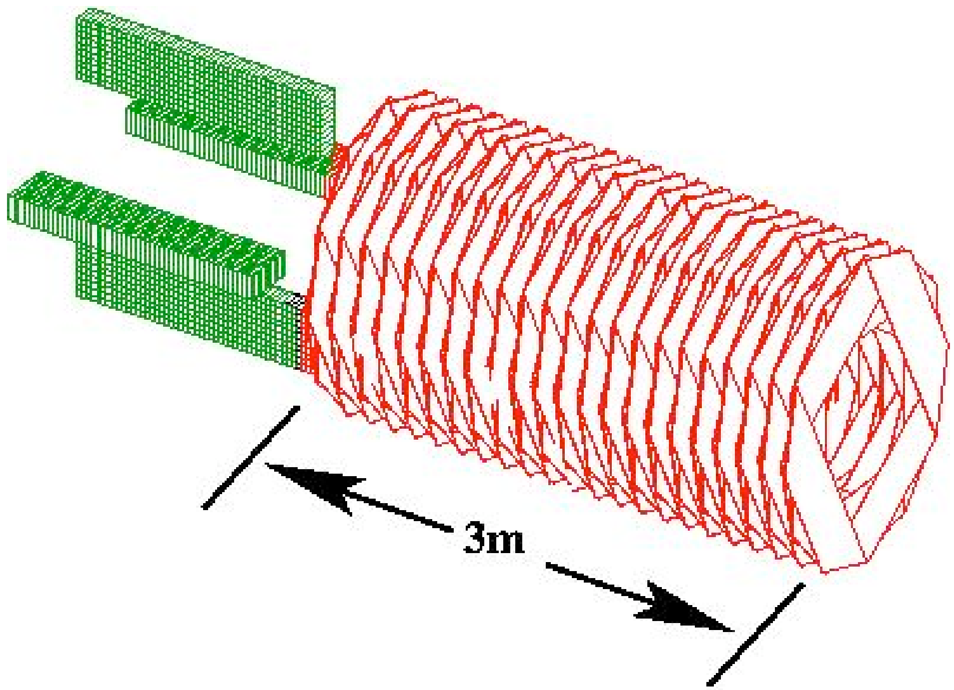




Tracker: 2880 axial straw tubes, 2.6 m by 5 mm, 25 µm thick carbon loaded capton. Longer than CKM straws!
Pad readout for position along the straw.
σ = 200 µm transverse and 1.5 mm in z.
Total about 20k channels.

Calorimeter: 1024 PbWO4 crystals, 3.5 cm x 3.5 cm x 12. cm. σ(E)/E≈5%.
Main use is for triggering.

Alternative: T-Tracker



- 260 sub-planes; 60 straws per.
- 5 mm diameter conducting straws
- Length from 70-130 cm
- Total of 13,000 channels

- L-Tracker
  - Not yet sure how to build it?
  - Meco Baseline
- T-Tracker
  - Robust pattern recognition may be harder?
- Need a fair head to head comparison.

Miscellaneous Parts List

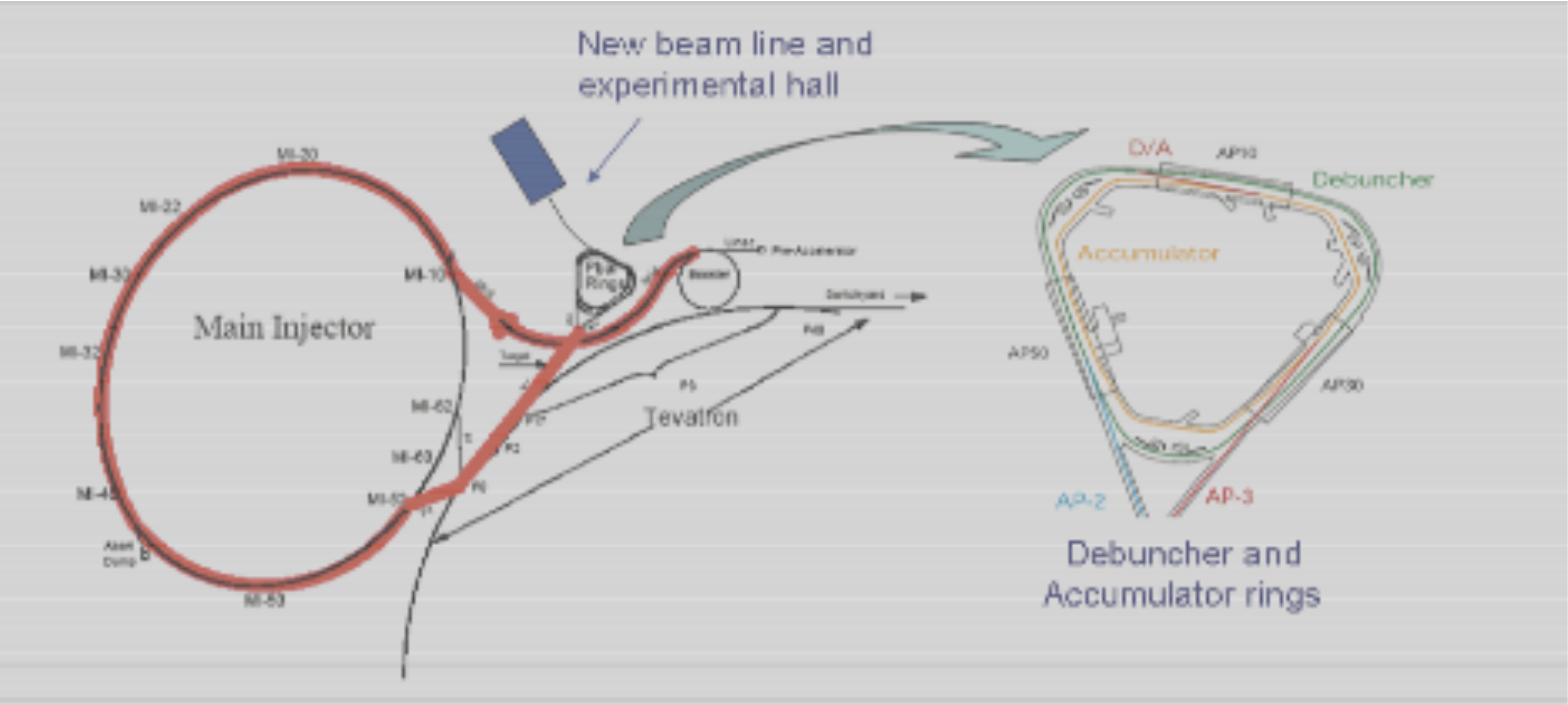
- Cosmic ray veto.
- Beam dump in middle of tracker.
- Ge detector to measure X-rays from muons stopping in the foils: cascade to 1s.
  - For normalization.
  - Views a tiny fraction of solid angle via a small hole in the beam dump. OK since the rate is very high.
- Proposal to measure resolution function directly:
  - 100 MeV electron accelerator to inject single electrons from downstream end.
  - Franken-accelerator from ILC/SCRF R&D parts?

Trigger

- MECO proposed a triggered design.
  - Trigger on ECAL, then read out straws and pads.
- Could we run waveform digitizers on 20k channels and sort it out in quasi real time?
  - Might not make triggering more efficient, but it should allow better background rejection.
  - Save money on crystals to spend on electronics and computing.
- No crystals makes easier interface with possible calibration accelerator.

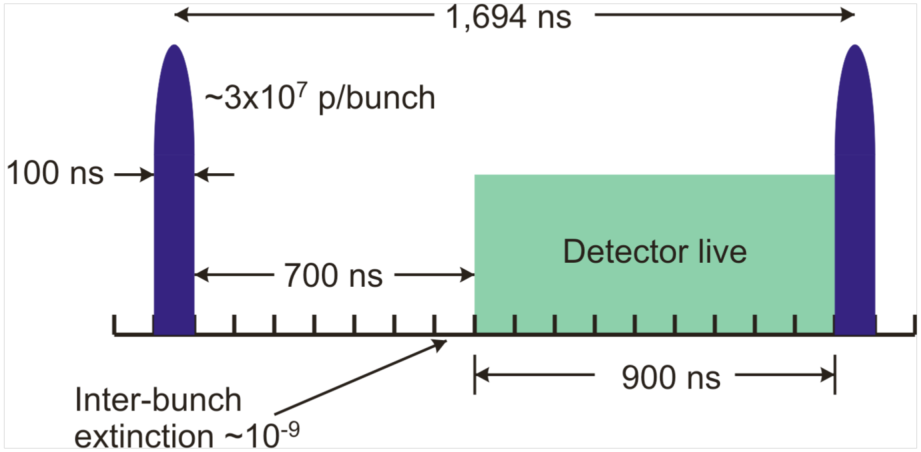
Proton Economics and Delivery

- Proposed NOVA supercycle: 20 Booster cycles.
  - 12 to NOVA; 8 available for other uses; Mu2e uses 6.



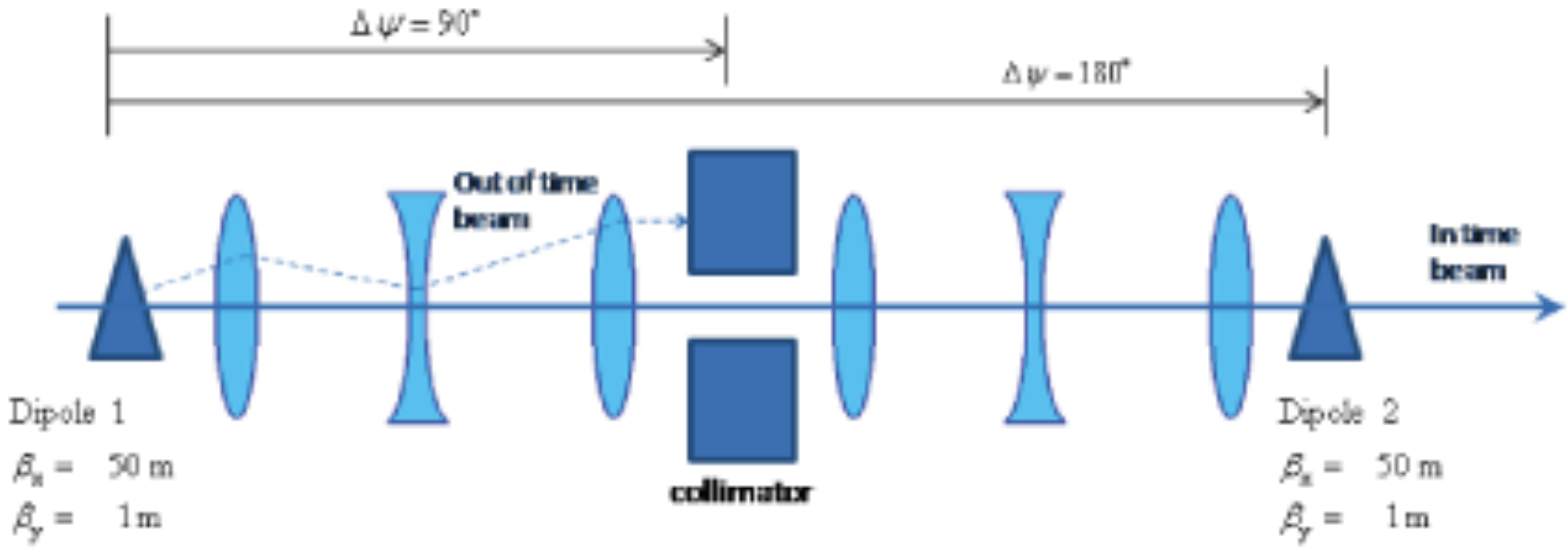
Bunch Structure

- "Momentum-Stack" batches in Accumulator
- Transfer to Debuncher
  - Rebunch into Single Bunch:
    - 38 nsec RMS, ±200 MeV
- Slow, Resonant Extraction:
  - Yields bunch "train".
- Overall 90% live time:
  - Off for 1/10 Booster cycles



Extinction Channel

- For each proton in bunch, need <10^{-9} between bunches.
  - Typical is 10^{-2} to 10^{-3};
- Preliminary design by AD.



Existing Software

- MECO legacy code. Reported to be fragile.
  – G3/Fortran spaghetti code.
  – All-in-one, event generator, beamline+detector simulation, reconstruction, analysis.
  – Magic numbers throughout.
  – SW for L and T Trackers are mutually incompatible.
- But: Important institutional knowledge
  – Low energy cross-section collected and built in.
  – Tuning of G3 to match data (which data?).
  – Special track fitters must be preserved in new world.
  – Do we need to use old code as a “calibration point” ??

Existing Software (2)

- Muons Inc has a G4Beamline simulation of the Mu2e magnet system from production target to physics target.
  - Does not yet contain detailed model of the dead material?
  - Interactions in material not tuned up.
  - Plot on page 13 made with this!
- Bob Bernstein has an initial crack at a G4 implementation of the detector.
- AD has tools to model extinction channel.

Who is Working on Software ?

- Mu2e masthead:
  - http://mu2e-plone.fnal.gov/mu2e-collaborators.html
  - 64 physicists (18 FNAL + 7 Muons Inc)
  - 17 Institutions
- Who will work on software:
  - Rob K. 50% until March 31, 2009, then increasing.
  - Andrew Norman, senior postdoc UVA, 25%.
  - Maybe Bob Bernstein at low duty cycle?
  - Tom Roberts, Muons Inc, G4 Beamline.
  - Expect more users once we have something to use.
    - Expect summer students and faculty.
  - Today: the bottleneck is the first step.

Short Term Goals – Feb 2009?

- Acquire modern code mgt, release mgt and distribution environment.
- Acquire a framework, geometry manager, persistency and related infrastructure.
- First G4 model of the detector.
  - It is important that the experiment have good models of the beamlines from upstream of the extinction channel to the beam dump. Not all needed today.
  - How to split the work with us, AD and Muons Inc.
- First reconstruction modules.
- Examples to get people started (C++ novices).

G4 Physics Models

- We will need to do a lot of work to validate and expand G4 physics models of interaction and production of low energy particles.
  - Start by incorporating work done by MECO.
  - Similar to the concerns that HCAL people have, but focused at lower energies.
- Vary models in a controlled way to estimate sensitivity of physics to these uncertainties.
- Feedback this information into G4?
  - Not yet discussed.

In the Long Run

- A modern G4/C++ implementation.
- Integrated description from upstream of the extinction channel to the detector.
  - Including neutron bath from production target, from dump, from extinction channel dump?
  - Track all hits back to their source, even noise hits.
    - Even if we will rarely use this it should be designed in.
    - Will pre-compute large background files.
- Will start with (physics target + detector).
  - But should define all interfaces early.
- Both triggered and un-triggered modes.

What To Do about MARS?

- For some interactions of beams with materials, that MARS is advertised as best available code.
- However we are permitted to only run binaries, not access sources.
  - Fortran, no cvs.
  - Binaries can change from underneath you!
- How do we interface to MARS if we have to?
  - What do we need to know/ do now to anticipate that?

Where are we Now? (1)

- Decided on:
  - SLF + gcc; maybe Mac OSX down the road?
  - CVS + SRT.
  - Dev version is not CVS HEAD if we can do so.
- Andrew Norman proposed fmwk framework.
  - MIPP, NOVA, SciBoone, MicroBoone.
  - He would like to ask CD to support it (ups/upd).
  - I have access to NOVA tutorials and will look at it.
    - Until I do so, I cannot say more.
- Other options: stripped down versions of Miniboone(without its Fortran support) or CMS.

Where are we Now? (2)

- Event IO
  - Expect to do the default root thing but have not yet seriously thought about it.
  - Want to make anything in principle persistable even if we rarely choose to persist it.
- Geometry:
  - GDML for nominal geometry.
  - Will not need alignment/calibration for a while.
- Databases
  - Do not anticipate early need for them but want to understand where they fit in and leave stubs ready.

A Key Early Decision

- Do we go with something simple fmwk as a "fast out of the blocks" option?
  - May be the fastest way to allow many to contribute.
- Or do we go with a stripped down version of a mature framework.
  - More pain now but big payoff down the road.
- My next job is to learn enough to make a recommendation on this.
  - Results may depend on support from CD.

Additional Information

- http://mu2e-plone.fnal.gov/index.html
- Docdb:
  - http://mu2e-docdb.fnal.gov/cgi-bin/DocumentDatabase/
  - Proposal: Mu2e-doc-388
  - Bob Bernstein's Wine and Cheese: Mu2e-doc-376